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The Future of Nuclear Tests

Hans A. Bethe and
Edward Teller

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The Future of Nuclear Tests

by Hans A. Bethe and Edward Teller

INTRODUCTION

by Vera Micheles Dean

ONE OF THE TOUGHEST FOREIGN POLICY DECISIONS that awaits the United States in 1961 is whether or not to resume nuclear tests, thus ending the unpoliced moratorium which has been unofficially in effect almost since nuclear negotiations began at Geneva on October 31, 1958 between the United States, Britain and the U.S.S.R.

When the Geneva conference resumed in September 1960 after a summer break, it became clear that the U.S.S.R. was unwilling to proceed with negotiations until it knew the outcome of the presidential election in the United States and the policy that would be adopted by the new Administration. As a dispatch from Geneva published by *The New York Times* of December 6 put it,

"With the present Administration unwilling to take policy decisions that would bind its successor, the United States was unable to make any move that would force the Soviet hand.

"The conference drifted into a deadlock that both sides tacitly conceded would not be broken until the presidential campaign was over and the President-elect had had time to pick up the reins of the negotiations."

To meet this situation, the United States on December 5 proposed that the nuclear test-ban talks be adjourned until February 7, and Britain and the U.S.S.R. agreed to this proposal. The United States delegate, Charles C. Stelle, told the conference on December 5: "A thorough review of United States policy toward this conference will have been made by the time that the United States delegation returns to this table in February."

Meanwhile, during the election, both Senator John F. Kennedy and Vice President Richard M. Nixon had made known their views about nuclear negotiations. On October 9 Mr. Kennedy had presented a six-point program on nuclear testing and disarmament. He then said that the United States would not be the first to resume tests in the atmosphere "to contaminate the air that all must breathe and thus endanger the lives of future generations." If the Geneva test talks were still going on, he declared, he would direct vigorous negotiations. If they had terminated, he would immediately ask Britain, France and the U.S.S.R. to begin a new conference. In either case he would prescribe a "reasonable" time limit to determine if there was significant progress. He would invite "leading nations having industrial capacity for production of nuclear weapons" to agree on "means of international control of both production and use of weapons grade fissionable material and also the production of nuclear weapons." And he would "earnestly seek an over-all disarmament agreement of which limitations on nuclear weapons

test, weapons grade fissionable material, biological and chemical warfare agents" would be an "integral part."

Mr. Nixon, for his part, had declared on October 26 that if he were elected he would ask President Eisenhower, on the day after election, to send Henry Cabot Lodge, former United States ambassador to the United Nations, to Geneva to negotiate with the Soviet Union about an atomic agreement. Mr. Lodge would be under instructions to seek a settlement with the Russians by February 1. If he and the Soviet negotiators were able to bring an agreement "in sight" within the 80-day period, Mr. Nixon said, he would be prepared to meet Premier Nikita S. Khrushchev and Prime Minister Harold Macmillan to make a final agreement at a summit conference. "In effect," reported Harrison E. Salisbury in *The New York Times* of October 27, "Mr. Nixon proposed giving the Soviet Union a virtual 80-day ultimatum after which the United States would resume underground nuclear testing if no agreement were in sight. However, he left the matter of actual resumption of testing somewhat vague. Mr. Nixon made a distinction between tests of peaceful atomic devices and tests for military purposes. He proposed that tests of peaceful devices be resumed if the 80-day period expired without progress toward agreement on a permanent test ban. He proposed that military testing not be resumed until an additional effort was made to achieve agreement."

Meanwhile, the danger that other countries beside the nuclear Big Three—the United States, Britain and the U.S.S.R.—might continue nuclear tests already started or undertake new tests was emphasized by two developments. On December 27 France staged its third nuclear explosion at the atomic proving grounds at Reggan in southwestern Algeria—an explosion which brought vigorous protests from several African countries, as well as the U.S.S.R. And Israel, with the aid of a foreign power reported to

be France, was said to be building a new nuclear reactor near Beersheba, which caused concern in Washington and other capitals—until Israel assured the United States government that this reactor would not be used to produce atomic bombs.

Whatever choice the United States makes about nuclear tests after January 20, 1961, our decision will have far-reaching repercussions on our relations with our allies, with the Communist bloc and with the uncommitted countries. To assure a hearing for arguments on both sides of this controversial issue, the FPA-WAC invited two distinguished nuclear physicists, Dr. Hans A. Bethe and Dr. Edward Teller, to present their respective views. Dr. Bethe's article is an expanded version of the one published in *The Atlantic Monthly* for August 1960, and copyrighted by that magazine. Dr. Teller's contribution is in answer to Dr. Bethe's original *Atlantic Monthly* article, but does not take into account the changes Dr. Bethe has introduced.

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The Case for Ending Nuclear Tests

by Hans A. Bethe

THE CESSATION OF NUCLEAR WEAPONS TESTS has become a major international issue. It is being debated in the newspapers, in Congress and, most of all, at the Big Three conferences in Geneva, where there have been what I consider honest negotiations. Concrete proposals have been made by both sides, by the East and by the West; there has been a considerable measure of agreement between East and West; and a number of articles for a nuclear test treaty have been agreed on.

Disarmament: With or Without Control?

However, the fundamental points of view of the two sides on disarmament measures are quite different. The U.S.S.R. has advocated the adoption of a document in which the United States, Britain and Russia would agree just to reduce their armaments. The United States and Britain have insisted on measures for the verification of any treaty concerning the limitation of armaments.

Because of Russia's desire for secrecy the West has proposed that the verification of a test-cessation agreement should be done primarily by technical methods which would mean less intrusion into the privacy of the Soviet Union.

It is clear that the Russians have by now accepted the major principle on which the United States has insisted, namely that there should be a control system for the test cessation agreement. This in itself is an important result of the negotiations and we must not jeopardize the achievement by either breaking off the negotiations, as some politicians have advocated, or by making unreasonable demands which we know Russia cannot fulfill.

METHODS OF DETECTION

The problem of detecting nuclear explosions varies with the medium in which the nuclear explosion is set off. Until recently, practically all the nuclear explosions were set off (either on the ground or above it) in the atmosphere. The best known method for detection of nuclear explosions is the collection of radioactive debris, either by planes flying in the air in those regions where the debris is expected to arrive or from the fallout on the ground. However, the collection of fallout on the ground is quite unreliable because the winds may carry the radioactive debris in one direction or another.

Many Kinds of Detection

We can also detect a nuclear explosion by the acoustic method, which consists of recording the pressure wave created by the explosion. As this wave goes through the atmosphere to distant points the pressure decreases, but it is still large enough even at distances like 10,000 miles to be easily recorded. The wave is such a good indicator of nuclear explosions that the United States has usually announced Russian explosions very soon after they have taken place. We have announced far more Russian explosions than the Russians themselves. Similarly, the Russians have been able to detect our nuclear explosions.

To improve detection, it is proposed, as part of a treaty on the cessation of nuclear tests, to have a large number of inspection stations in each country, especially in Russia, in the United States and in the British Commonwealth. With the network of stations agreed on during the Geneva negotiations it is generally

believed that we would be able to detect and identify explosions in the air down to the level of one kiloton or possibly lower.

The second medium in which nuclear explosions have been set off is under water. Such explosions are if anything even easier to detect than those in the air because the pressure wave is very well transmitted through water, so much so that even an explosion of a few tons can be recorded through water for thousands of miles.

Nuclear tests might also be carried out in outer space. Detection there is considerably more difficult than in the air or in water. Much thought has been given to this problem to which I will return later in this article.

Underground Testing Problems

Our most vexing problem is underground testing, which has received the most publicity. It has the obvious advantage that it does not contaminate the atmosphere but also the great disadvantage that from a detection point of view it is therefore impossible to collect radioactive samples. From experience gained in Nevada we know how deep an explosion has to be buried in order to prevent escape of radioactive material into the air. A kiloton bomb must be buried about 400 feet underground, a 20 kiloton bomb about 1,100 feet.

The displacement of the earth produced by an underground explosion is sufficiently great to be easily recorded by a seismograph unless the explosion itself is very small. The two largest underground explosions to date were carried out in Nevada in the autumn of 1958, one of 5 and the other of 20 kilotons; they could be observed on the seismographs throughout the United States, and the larger one gave a clear record in Russia.

Earthquakes and Explosions

Unfortunately, underground explosions produce the same type of record as earthquakes, namely seismograms consisting of a series of perhaps 20 wiggles. There are very few distinguishing

marks between the two types of seismogram. The best that seismologists have been able to find is the so-called first motion, namely whether the first wiggle starts up or down.

The criteria for distinguishing earthquakes from explosions have been discussed in detail during the Geneva negotiations. It has been decided that control stations should be set up at regular intervals of about 600 miles in seismic regions—i.e. regions in which earthquakes normally occur, and about 1000 miles in regions not subject to seismic occurrences. This means that about 20 stations would be set up in the U.S.S.R.

It is estimated that some 100 to 200 earthquakes which have a force equivalent to that of an explosion of 20 kilotons occur in the Soviet Union every year. Of these, about half would be distinguished from explosions by first motion and other features in the seismograms obtained in the proposed network of stations. This leaves about 50 to 100 earthquakes a year which could not be distinguished from explosions.

How Much Inspection Needed?

The only sure way to tell an earthquake from an explosion is to send an inspection team to the location of the earth disturbance. A combination of seismograms from the several stations can determine the location to an accuracy of about five miles. Thus one would have to send an inspection team to explore an area of about 100 square miles to comb it for evidence of an explosion. A number of scientists have tried to work out procedures for such an inspection.

How many inspection teams will have to be sent out every year? As already pointed out, there are annually about 50 to 100 earthquakes in the Soviet Union which on the seismograph look like explosions of 20 kilotons or more. It is generally agreed that it would not be necessary to investigate each and every one of these events. Thirty percent of the questionable ones would suffice. Under the proposed Geneva system, this would mean that about 20 inspections must be carried out in the Soviet Union each

year in order to monitor possible nuclear tests above 20 kilotons.

A more detailed study of this problem has been made by Dr. Richard Latter of the Rand Corporation. He finds that the capability of the control system would be greatly increased by distributing the stations somewhat differently from the Geneva proposal and by increasing their number in Russia from 20 to 30. This would make it much easier to distinguish earthquakes from explosions, so that only about ten earthquakes a year in the Soviet Union with a force equivalent to 20 kilotons or more would remain unidentified by their seismograms. Ten inspections would therefore cover all doubtful events equivalent to 20 kilotons or more. Forty inspections would make it possible to monitor all earthquakes above 5 kilotons. (A 5-kiloton bomb is a small bomb. The Nagasaki bomb had a force of 20 kilotons.)

Possibility of Concealment

We must keep in mind, however, that explosions can be purposely concealed. Our underground explosions in the past have been carried on in Nevada tuff, a rock which is very soft and therefore gives a relatively strong seismic signal. If the underground explosion is carried out in harder rock, such as salt, granite or limestone, a smaller signal is received. A signal which corresponds to a 5-kiloton explosion in tuff may correspond to perhaps 10 or 15 kilotons in these harder types of rock. Even 15 kilotons is not a very large atomic explosion.

Our capability of detection and inspection of underground explosions under the Geneva or the Latter system would thus be quite satisfactory if it were not for the possibility of deliberate concealment of explosions. A very powerful method of doing this has been suggested by Dr. Albert L. Latter, the brother of Dr. Richard Latter. The method, known as "decoupling or muffling," consists of making an enormous cavity underground and setting off the atomic bomb in the middle of that cavity. It is estimated that the apparent size of the explosion is thereby reduced by a factor of about 300 if the hole is made in hard rock.

'The Big Hole'

Latter's decoupling theory was invented about January 1959 and checked by many scientists, including myself. It was experimentally verified with small explosions of conventional high explosive in Louisiana early last year. To decouple the explosion of a 20-kiloton weapon you need a spherical hole of about 50 million cubic feet, or nearly 500 feet in diameter. Moreover, the hole must be 3000 feet below ground. The Big Room of Carlsbad Caverns, for example, is only big enough to muffle ten kilotons.

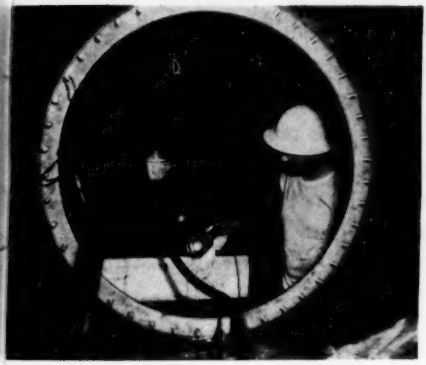
It would obviously be very slow and very expensive to excavate a larger hole by a normal mining operation, with pick and shovel and high explosives. However, in so-called salt domes, large holes can be made by washing out the salt, i.e., by pumping water in and brine out. Experts of the oil industry have estimated that to excavate a hole big enough to muffle a 20-kiloton explosion would take more than two years and would cost about $10 million. This requires a good deal of money, but the time factor is probably more important. The actual washing operation must be preceded by an engineering study, and after completion of the hole considerable time is required to set up and complete an atomic test.

Whether a 500-foot hole in a salt dome could stand up is not known. Holes of about one-tenth that volume are used to store oil and gasoline. It is also not known whether a hole could be used repeatedly for nuclear testing.

I cannot imagine that the washing of a 500-foot hole would go undetected even in a closed country like the Soviet Union. For one thing, the amount of salt water which would be carried up to the earth's surface is staggering, being many times the volume of the salt. Somehow this salt water must be disposed of. It has been proposed to dump the brine directly into the sea or into depleted oil wells, but both of these methods severely limit the geographical areas in which the hole could be constructed. A more widely applicable method is to dump the salt into a river. But even in a very big river, like the Ohio or the

48" lucite sphere for 2000 lb. shot on test stand prior to assembly in the cavity ▶

View of 12 ft. diameter sphere showing 48" diameter lucite explosive container in place ▼



View in the vicinity of entrance drift to 12 ft. diameter sphere ▼

These photographs depict various phases of the Cowboy operation to measure the decoupling of an HE charge in a large hole in salt compared to one closely tamped in salt, conducted by the Lawrence Radiation Laboratory.

Courtesy, the U.S. Atomic Energy Commission

St. Lawrence, the salt excavated from a single big hole would double the salt content for a whole year. This would be very easy to discover by making a chemical analysis of the river water, and I assume that the Russians probably would have no objection to such analysis.

It is important to note that there are relatively few locations in which large holes can reasonably be dug—salt domes are needed, as well as ways for disposal of the salt water. In other types of rock both excavation and disposal of the excavated material would be far more troublesome. In addition, the resulting hole would be less safe and less reliable for decoupling. The geographical regions where salt domes are known to exist are generally aseismic, that is, not subject to earthquakes, so that any seismic signal originating from these regions would be suspicious, thus obviating identification of the seismic signal and requiring only a few inspections to guard against muffled shots. Of course, one must first get a signal from a muffled explosion. How this can be done I shall discuss later.

Russian Scientists Sincere —

Two main questions are, Does any country want to go to such extremes as construction of the big hole in order to cheat on a test ban? Can we really assume that the Russians would go to such pains to negotiate a test cessation treaty just in order to turn around the next day and violate it?

Having participated in the negotiations with the Russian scientists at Geneva on three occasions, I believe that they are sincere in wanting the nuclear test cessation agreement and do not intend to cheat on it. I believe this on the basis of conversations which I and many other American scientists have had with Rusian scientists, both in Geneva and elsewhere. Many of these conversations were quite relaxed and the Russians gave every indication of being frank. They showed a deep concern about the arms race and a desire for peace, arms limitation and test cessation. But, in addition to these personal conversations, we

also have some objective indications from the Geneva negotiations to the same effect. The Russians have been hard bargainers in these negotiations, especially when they have insisted on parity in representation on the International Control Commission, and when they have tried to reduce the entrance of foreign inspectors into their territory. But they have always been eager to accept any improvements in detection apparatus suggested by the United States. If the Russians wished to violate the treaty, they would have objected to these improvements.

— But Many Americans Doubt This

Many other Americans, without disagreeing on any of the scientific facts, believe that the Russians are bent on violation, and they therefore oppose the cessation of testing. Their line of reasoning runs about as follows: We cannot detect Russian underground tests of bombs of small yield; since we cannot detect these tests we should assume that they are carrying out such tests. If they carry out such tests and we do not, then they will soon be ahead of us in the area of small nuclear weapons. When they are ahead of us in this area, they will have military superiority and thereby can blackmail us into complete submission. At that moment the whole free world will have to capitulate to Russian communism.

It seems to me that this is a series of *non sequiturs.* In particular it greatly overestimates the importance of atomic weapons. Our military strength is made up of many different components, of which atomic weapons are but one. Means of delivery like planes and rockets are another important component; so are radar, communications, decision-making, transportation and many more.

Atomic weapons are the most developed of all these components of our military strength, and I shall have to say more about the prospect of future developments in this field later on. Among atomic weapons, the big hydrogen bombs are the main part of our deterrent. By contrast, tactical weapons are only a moderate

fraction of our atomic armaments—and we already possess a big arsenal of tactical weapons. To claim that the Russians would be supreme if they could achieve superiority in this one fraction of one area of military preparations seems to me very far-fetched.

To achieve this superiority the Russians would have to violate the proposed treaty banning weapons tests. I do not think the Russians could risk such a violation even if there is only a small likelihood of detecting the tests. Even if we had no system of physical stations detecting nuclear tests, the Russians would not risk having some defector tell us about a clandestine nuclear explosion. If there were such a defector telling us of a Russian violation, it would not be very difficult to find physical evidence of it. I believe the Soviet Union, which is posing as a peace-loving nation—whether sincerely or not—simply cannot afford to be caught in a violation, and therefore I think the Russians will not try to cheat.

Cheating Would Not Help

But even suppose that the Russians did cheat, what would they need to do? One violation, one nuclear test below ground, does not do much for the development of weapons. In the first place, they would have to develop entirely new methods to assess the results of a nuclear test. Most of the methods commonly used for observing the results of a test in air do not work underground. Probably several explosions of weapons whose performance is already known are required to develop methods of observation underground. Secondly, two or more test explosions are often needed to develop a single new weapon. Finally, a country which already has dozens of types of weapons will hardly be interested in developing just one more, in violation of a treaty. For all these reasons, a potential violator of the treaty would only be interested if he could perform a whole series of tests.

If a series of tests were carried out, all at the same location, this would greatly simplify the work of the detecting agency. It would merely be necessary to detect the disturbances on the

seismograph, not to distinguish them from earthquakes. The fact of repeated seismic disturbances originating from the same location (except as aftershocks of one big earthquake) would be sufficiently suspicious to cause dispatch of an inspection team to their site. If the proposed Geneva system of 20 stations in the Soviet Union is accepted, it is generally agreed that we could record disturbances underground of less than one kiloton. Thus, to violate the treaty without being detected, it would be necessary to find a new location for practically every test in the series. The development of a new test site adds enormously to the cost, complexity and inconvenience of testing.

I had the doubtful honor of presenting the theory of the big hole to the Russians in Geneva in November 1959. I felt deeply embarrassed in so doing because it implied that we considered the Russians capable of cheating on such a massive scale. I think they would have been quite justified if they had regarded this as an insult and had walked out of the negotiations in disgust.

The Russians seemed stunned by the theory of the big hole. In private they took the Americans to task for having spent a year in inventing methods to cheat on a nuclear test cessation agreement. Officially they spent all their efforts in trying to disprove the theory of the big hole. This is not the reaction of a country which is bent on cheating.

Two of the Russian scientists presented to the Geneva conference their supposed proof that the big hole would not work. A day or two later Dr. Latter and I gave the counterproof and showed with the help of the Russian theory itself that the Russian proof was wrong, that in fact the theory of the big hole was correct. We have been commended in the American press for this feat in theoretical physics. I am not proud of this achievement.

In the April 1960 congressional hearings before the Joint Committee on Atomic Energy, Dr. Teller recommended that we in the United States should continue determined research to find further methods of decoupling, further methods of reducing the

signal from an underground explosion. His argument is that we have to know all the possible methods of concealment if we are to develop a detection system which can deal with them. This may be so, but should we really spend our time and effort in drawing up a blueprint for a violator of the treaty and also doing the engineering development for him?

The Russians themselves have been quite consistent in their attitude toward decoupling. As recently as the May 1960 negotiations at Geneva for joint research on improvement of seismic detection, they refused to participate in any research on decoupling or to permit the United States to engage in such research. "The Russian people," said Semyon K. Tsarapkin, the U.S.S.R. delegate, "will not understand it if research under the test ban treaty is conducted for the purpose of defeating the treaty."

SEARCH FOR IMPROVED METHODS

Because of the difficulties of detecting small nuclear tests underground, the United States in February 1960 proposed to the two other great nuclear powers that for the time being they conclude only a partial test ban treaty. Tests in the atmosphere and underwater, as well as in the nearer parts of outer space, would be discontinued. Underground, the United States proposed to ban all large nuclear explosions, namely those giving a signal equivalent to 20 kilotons or more under Nevada conditions. Smaller explosions and decoupled tests would be permitted.

Further, the United States proposed that the three powers should start intensive research on the improvement of methods for detection and identification of underground explosions so that in time the treaty could be extended to smaller underground explosions, and perhaps a complete ban could be concluded in the end.

This proposal was accepted by the U.S.S.R. on March 19 with an important modification, namely that there should be a

moratorium on smaller nuclear tests for a number of years. While only the large tests would be prohibited in the treaty itself, the three powers would declare in a separate document that they would refrain from carrying out nuclear explosions under 20 kilotons. The Russians proposed four to five years as the duration of such a moratorium, the West two to three.

To examine this proposal further, the seismologists of the three nuclear powers met in Geneva in May to make plans for joint research on seismic detection. A large measure of agreement was achieved, but there is still a question as to the number and type of nuclear explosions to be used in this research.

Somehow the seismic research has become identified in the mind of the public with the setting off of underground test explosions. This is by no means correct. The main problem is to improve the instruments of detection. This can be done largely by utilizing signals from earthquakes. For this purpose few explosions will be needed.

Better Instruments Needed

We need instruments which can give us more diversified information. We want to eliminate from the seismograms as far as possible the "noise"—that is, the ever-present, minute, irregular motions of the earth. We need to learn to utilize calculating machines and mathematical tricks for the analysis of the records. We want to deduce the original earth motion due to the earthquake or explosion from the observed seismogram, taken hundreds or thousands of miles away. For instance, we would like to know the depth of the earth disturbance below the surface. At present the depth can be deduced from the seismogram only if it is very great, about 30 miles or more. Perhaps we can learn to determine the depth of the source of the seismic signal to an accuracy of one mile. If this were possible then signals originating from a depth of at least two miles could be attributed to earthquakes because it is extremely difficult to drill holes as deep as that.

The Berkner Panel

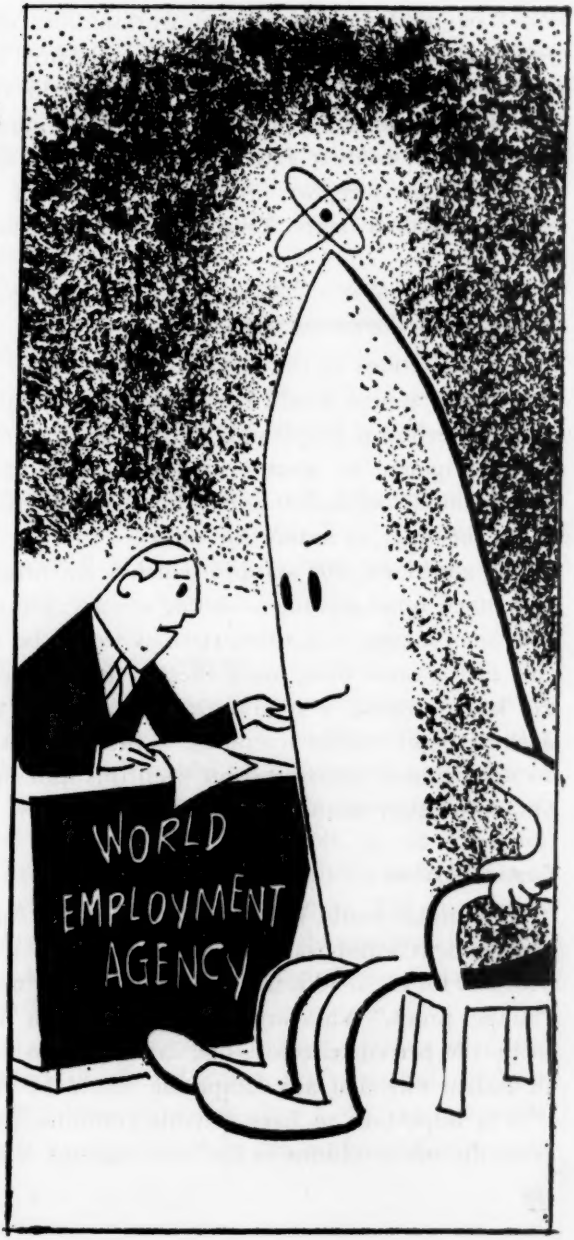
A number of promising ideas for improved detection were proposed in June 1959 by the Panel on Seismic Improvement, under the chairmanship of Dr. Lloyd Berkner, which was set up by the Special Assistant to the President for Science and Technology at the request of the State Department to study the problem of detection of nuclear explosions. Some of these ideas seemed certain to such an extent that they were proposed to the Russians at the technical conference in November 1959. A lot of research will have to be done to translate these ideas into practice. There is good hope for substantial improvement of the art of detection during a two- or three-year moratorium.

Will it be possible by these improvements to detect a decoupled test of a 20-kiloton explosion in a big hole, using only the 20 seismic stations provided in the Geneva system? We do not know. It must be borne in mind that with a decoupling factor of 300, a 20-kiloton explosion looks like only about 70 *tons,* not *kilotons,* and this is a very small explosion indeed. With the present methods the Geneva system can only detect and locate explosions down to about 700 tons, but not identify them.

But suppose it is impossible to improve the seismic technique sufficiently. We already know one method which would certainly enable us to detect even the fully decoupled tests. This method is to make the spacing between stations much smaller. In Geneva it was agreed that the spacing between stations should be about 1000 miles in the aseismic regions and about 600 miles in seismic regions. My proposal would be to decrease the spacing to 120 miles in the seismic regions and also in those regions where there are salt domes. In the parts of the Soviet Union where there are neither earthquakes nor salt domes the stations could be distributed at a much greater spacing, let us say 250 miles. With these spacings one would need about 200 stations to cover the Soviet Union.

If the whole of the Soviet Union, seismic and aseismic regions alike, were covered by stations at 120-mile spacing, 600 stations

NUCLEAR POWER FOR PEACE



'I've got a job at an electric plant for you.'

Langley in *The Christian Science Monitor*

would be needed. I mentioned this number during the congressional hearings which were held in April 1960 under the chairmanship of Representative Chet Holifield, chairman of the Special Subcommittee on Radiation. The number was then quoted out of context and without the proper qualifications in sensational press reports which implied that I no longer supported a test ban treaty. This, of course, does not correspond to the facts.

Manned and Unmanned Stations

The 20 stations in the U.S.S.R. which would be provided by the Geneva system would be large, manned stations, each with about 30 technical people plus supporting personnel. They would have equipment to observe nuclear tests in the air as well as underground, and each station would have an array of 100 seismographs in order to reduce the noise.

The additional 200 stations which I am proposing would be unmanned robot stations with one seismograph each, or possibly two. Such a system of robot stations would be simpler, cheaper and, at the same time, more effective for seismic detection than the large stations. I should think that these additional robot stations might well be acceptable to the Russians, especially if we do not demand them now but keep this idea in mind as a way out if no better method is discovered to observe decoupled tests.

Cost of System

How much would such a system of small stations cost? Two independent estimates have come out with a figure of about $100,000 for each. This includes provision for making the station "tamper proof." While one cannot expect such "tamper proofing" to be 100 percent effective, one can expect to design the station in such a way that any tampering would be visible.

It is important to have reliable transmission of information from the robot stations to the large stations. Various methods of

transmission have been considered by a group of communications experts. The total cost of the system of small stations in Russia, even with the most elaborate communication links, is estimated to be less than $20 million. Engineering estimates have also been made of the cost of the basic 20-station net. No final figure has been given, but a total of $500 million for both the small and the large stations is probably the best conservative guess that can be made at present.

The system of robot stations is expected to detect and identify fully decoupled 20-kiloton tests in the seismic regions. It is expected to detect and locate, but not identify, similar tests in the aseismic regions. I have previously shown that, once you get a signal, the number of inspections can be held within reasonable bounds.

It has been argued that several years will pass before we can build the system of small robot stations. This is true, but it would also take several years before a large cavity could be constructed and successfully used.

Small-Weapon Testing Might Continue

In the meantime there is a possibility of using already existing smaller cavities in salt. There seem to exist, at least in this country, several holes which would fully decouple an explosion of two or three kilotons. If similar cavities exist in Russia, it must be admitted that it would be possible to use these for testing such very small weapons—there will always be a threshold of detection even with the best detection system. The question is whether such testing would be worth while. Moreover, a 2-kiloton hole could be used to achieve partial decoupling for a larger explosion, let us say 20 kilotons.

From the Louisiana experiments one may estimate that this proportion of hole to size of explosion will give decoupling by a factor of 30. The 20-kiloton explosion then looks like two-thirds of a kiloton. This is just detectable by the proposed Geneva net

of stations, although, without the robot stations, a signal of this size could not be distinguished from an earthquake. Thus, with the Geneva net alone, it would be risky for a violator to attempt a partially decoupled explosion of 20 kilotons. A 10-kiloton explosion, partially decoupled in an existing 2-kiloton hole, could probably go undetected until either we have robot stations or significant improvements have been made in the art of detection. However, it would seem from the Louisiana experiments that the cavity will suffer damage when it is used for partial decoupling of an oversized explosion and it is very doubtful whether it could be used more than once. In this way the few existing big holes would soon be used up.

I therefore believe that it is technically feasible to devise a system of detection stations and inspections which will give reasonable assurance against clandestine testing, with the possible exception of very small decoupled tests.

What About On-Site Inspection?

A key point in the monitoring system is on-site inspection. This was recognized as necessary at the Conference of Experts in Geneva during the summer of 1958. The Russians agreed reluctantly—but they did agree—to a passage which says "that all events which are recorded by the control stations and which could be suspected of being nuclear explosions will have to be inspected on the site." This passage, which our negotiators insisted on, has been a very powerful argument in our hands. I am sure that the Russians have often regretted that they agreed to this passage. On the other hand, our delegation would not have agreed to the final report of the conference without this passage.

Estimates made in Washington have ranged as high as 100 to 300 necessary inspections per year in the U.S.S.R. for a complete test ban. Obviously Moscow wishes to prevent such a large number of inspections. Soviet negotiators have objected time and time again on the ground that we would use the on-site inspections

for espionage purposes. This is one of the unfortunate consequences of the Kremlin's obsession with secrecy, and on this point there has been a lot of disagreement between the West and the East.

Macmillan Suggestion

To solve this impasse, British Prime Minister Harold Macmillan, on his visit to Moscow in the spring of 1959, proposed that there should be a fixed quota of inspections every year in each country and that in exchange each side should have free choice of the inspections to be made on the territory of the other.

In other words, if a suspicious event should be recorded on the seismographs in Russia, then the West, which means essentially the United States and Britain, would have the right to choose whether or not to inspect this event. They would decide on the basis of other knowledge whether it is reasonable in that particular locality to suspect a nuclear explosion. If, for example, the seismic event is shown to originate from a completely trackless wilderness in the mountains, then it may be presumed by the West that it was not a nuclear explosion. If, however, the seismic event is recorded in an abandoned mining area where one might very easily dig a tunnel to put in a nuclear bomb for testing, or especially in a salt-dome area, then we would presumably insist on inspecting that area.

Good Compromise

It seems to me that this idea of a quota, combined with free choice by the West of the events to be inspected in Russia, is a good compromise. Russia has accepted this idea; in fact it did so before our own government. The two sides, however, cannot agree on which basis the quota should be fixed. Our government insists that the quota should be determined on the basis of technical need, so as to give assurance that an adequate percentage of the suspicious events can be inspected. The Russian position

is that the quota must be determined on the basis of political acceptability alone.

In practice, however, our government has adopted the quota idea, as part of the United States proposal of February 11, 1960 of a partial ban on nuclear tests.

It proposed that this partial test ban be enforced by a quota of about 20 inspections a year in the U.S.S.R., a very reasonable number. The Russians, after accepting the February 11 proposal with some modification, took a long time to suggest a definite number of inspections. In July they gave such a number—when they finally suggested three inspections per year in the U.S.S.R.—a number which is entirely inadequate. We have to insist on a number much closer to our proposal of 20.

Testing in Space

Even though the testing of atomic weapons in space has received less public comment than underground testing we must mention here the possibility of carrying out such tests. In the framework of the Geneva conference technical discussions on space testing were held between the East and the West in the summer of 1959. In these discussions it was agreed that it is technically feasible to test atomic weapons in space. The technical experts also agreed that a detection system could be devised which would be able to detect most of the nuclear explosions that might be conducted in "near space"—that is, up to distances of about a million miles from the earth—and most of the large explosions in "far space."

Atomic weapons tests in space, like those underground, have the advantage that radioactive contamination of the atmosphere can be avoided unless the test is conducted very close to the earth. If a country wished to conduct such tests it would have to design an artificial satellite which, at some predetermined point in outer space, could be separated into two parts, one carrying the bomb and the other carrying detecting equipment and a radio transmitter to transmit the results of the test back to the earth. These

two parts might be separated by about five to ten miles, and then the bomb would be set off.

Satellites Must Be Used

It should be possible for both the United States and the U.S.S.R. to design such satellites. Of course it would probably take several trials before such a system would function reliably. Once such satellites have been developed they could be sent either to near space or to far space, up to distances as vast as about 200 million miles—that is, more than twice the distance of the sun from the earth. The only added difficulty in attaining such large distances would be that the radio transmitter would have to be quite strong, and this would increase its weight and complexity. Moreover, a country which wished to conduct a test at 200-million-mile distances would have to wait approximately a year before its satellite would attain such a distance. Obviously this would greatly slow down testing, especially if we bear in mind that in many cases a complex satellite system might not function properly. Much simpler rocket launchings have frequently failed.

Weapons tests in near space can properly be detected by a suitably designed detection system based on the earth. To detect tests farther away it is necessary to put the detection system also on satellites. In fact it would be most advantageous to have six satellites circling the sun rather than the earth, all equipped with special detectors. These satellites would of course also have to transmit information by radio to the earth. The problem of putting up detection satellites is rather similar to the problem of conducting weapons tests in far space.

Possibility of Using Shields

If no special precautions are taken in the weapons tests, then it should be possible, by means of solar detection satellites, to observe weapons tests at extreme range (200 million miles) with a yield of about 50 kilotons or more. However, as is the case

underground, the potential violator of a test ban agreement would have the option of purposely concealing his explosion from the detection satellite by suitably designed shields. These shields would be heavy and would make testing in space more difficult, more complex, more expensive and less reliable. Such shields, however, may make it possible to conceal explosions up to about one megaton (1000 kilotons) in far space even from the best detection system we can at present conceive.

Both testing and detection in space will be expensive. Both will probably take years to develop. Once this testing method has been developed, a determined violator could test weapons up to about a megaton without being detected—as long as all parts of the system function properly. Thus the detection system in this case cannot prevent clandestine tests in space; it can only limit the yield, it can make tests very expensive and, most important, it can greatly slow down the rate at which tests can proceed.

Probably the best way to deal with space tests would be to permit international inspection of the payload of all space vehicles that are launched. The fact that a launching has taken place can be ascertained rather easily. It may be rather difficult, however, to get the Russians to agree to payload inspection just for the purpose of a test-cessation agreement. They might be more willing to do this in the framework of a more comprehensive disarmament agreement.

U.S. Now Far Ahead in Tactical Weapons

Let us assume the most unlikely and worst possible case, namely that the Russians have gone to all the trouble of negotiating a treaty only in order to violate it. It would take them a very long time to cause any significant number of explosions; it would cost them a tremendous effort. As long as they stay underground and do not make use of space testing, they could only test small nuclear weapons. Even in the area of small nuclear weapons a test series would take a number of years. Now let us even assume that the

Russians wish to go to all this trouble just to develop further small nuclear weapons. Where do we stand?

At this time there is reason to believe that we are far ahead of Russia in the development of small nuclear weapons. We have nuclear weapons from 20 kilotons down to a fraction of a kiloton. We have them in all different sizes. We have weapons which can be carried in big airplanes, in fighter planes, in ballistic missiles, in land-based rockets and even in airborne rockets to bring down enemy planes. We have nuclear weapons which can be shot in short-range rockets such as the Honest John; we have nuclear weapons so small that they can be carried by the infantry with relative ease. We have an enormous arsenal of such weapons. The Russians have a number of such weapons as well, but their arsenal in the field of small weapons, so far as we know, is much more limited than ours, and probably their weapons are not quite as sophisticated. It would take them a long time to catch up with us.

ALTERNATIVES TO TEST CESSATION

What is the alternative? Suppose we resume tests only in the area of small weapons. Then we could be sure that it would not take the Russians very long to reach our present, very high-level technology in this field. But it will be argued that in the meantime we also can make progress. Clearly we could if we resumed nuclear tests. However, we have already gone far enough so that very little we can do in the future will be of great military significance.

While the Russians could gain considerably by the resumption of tests of small nuclear weapons, they also have enough such weapons to give them a sizable capability in case of a tactical nuclear war. Therefore they do not have a desperate need for improving their weapons, and thus not enough incentive for testing to risk a violation. Yet if nuclear tests were resumed legally, the Russians would probably make more rapid progress than the United States.

Is Further Testing Worth While?

It has been claimed that we still have a long way to go in tactical weapons. There are two schools of thought on this; one primarily represented by the Livermore Laboratory at the University of California, the other by the Los Alamos Laboratory. The Los Alamos Laboratory, our chief laboratory in the development of nuclear weapons, which has to its credit most of the weapons that have been developed up till now, is generally of the opinion that we have reached very nearly the end of the road, that not much more can be obtained in the way of weapons improvement. They will admit, and I will admit, that you can always make some further improvement, but here arises the question, Is it worth while? Is it worth as much as a treaty which might be the first step toward peace?

Let me repeat: If the Russians really want tactical nuclear weapons, that is nuclear weapons of small yield, then the best thing for them to do would be to resume testing of such small weapons officially, exactly as was suggested in the original proposal by the United States on February 11, 1960; that is, under a program of joint research by the United States, Britain and the U.S.S.R. The fact that they did not accept President Eisenhower's proposal without change, the fact that they asked for a moratorium on small tests, indicates to me that they do not give much weight to development of these weapons.

I believe that if tests were resumed, if the negotiations on test cessation were to break down, then the Russians would choose to test big weapons, hydrogen weapons, in the megaton class. I think these are the weapons which are most dangerous to us; these are the weapons which the Soviet leaders consider as being of the greatest military importance to them. Let us recall the situation in the autumn of 1958. At that time the United States put in an extra test series which is known as the Hardtack II series, carried out in Nevada. This test series consisted of a number of small nuclear explosions from about 20 kilotons on down to a fraction of a kiloton.

At the same time the Russians tested the largest weapons they have ever tested, weapons of many megatons. They increased the yield from their weapons; they made them more efficient in the large megaton variety. They probably obtained in that test series the warhead for their big intercontinental ballistic missile. This is a tremendous weapon in their hands. This is a weapon of which we have to be much afraid. If the Russians were to launch a determined attack on this country, perhaps a surprise attack, they would undoubtedly use these enormous weapons.

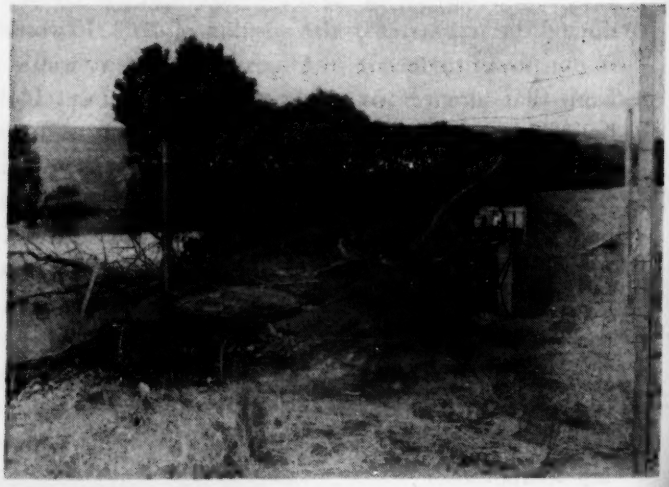
1958 Tests to U.S. Disadvantage

It was greatly to our disadvantage that the United States conducted the test series in the autumn of 1958. It would have been in our power to declare in August 1958 that we would stop testing from that moment on. If President Eisenhower had made this bold declaration, I do not believe that the Russians would have conducted their test series in September and October. They used our small test series as a very welcome excuse to conduct their own. This is an example where the bold political decision to stop tests altogether would have been much more advantageous to us militarily, since such a decision would have made it difficult for the Russians to resume testing and to test their big warheads. If they had done so nevertheless, we would still have been free to conduct the small Hardtack II series. We got comparatively little from that small test series; they got a great deal, in terms of very big weapons.

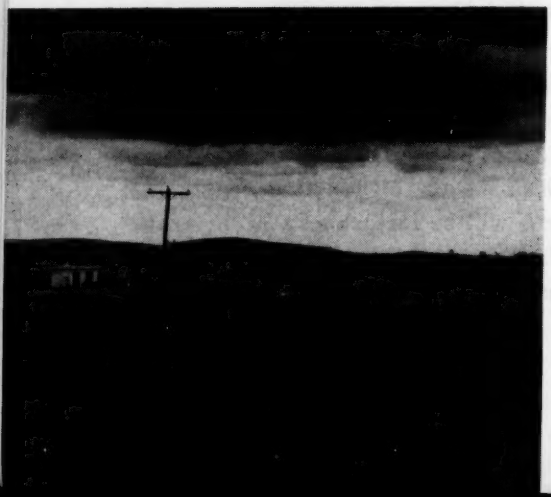
If we were now to resume testing, if we were to break off negotiations in Geneva, then we could not force the Russians to test only small weapons underground. While we might restrict our own testing in this manner, the Russians would feel free to test anything that they consider to be to their military advantage. They would almost certainly make the biggest tests which they consider useful. Whether these will be further tests in the multi-megaton category or whether they would try to decrease the weight for let us say a one-megaton weapon, this I could not

Typical large underground vault, which contains four types of seismometers

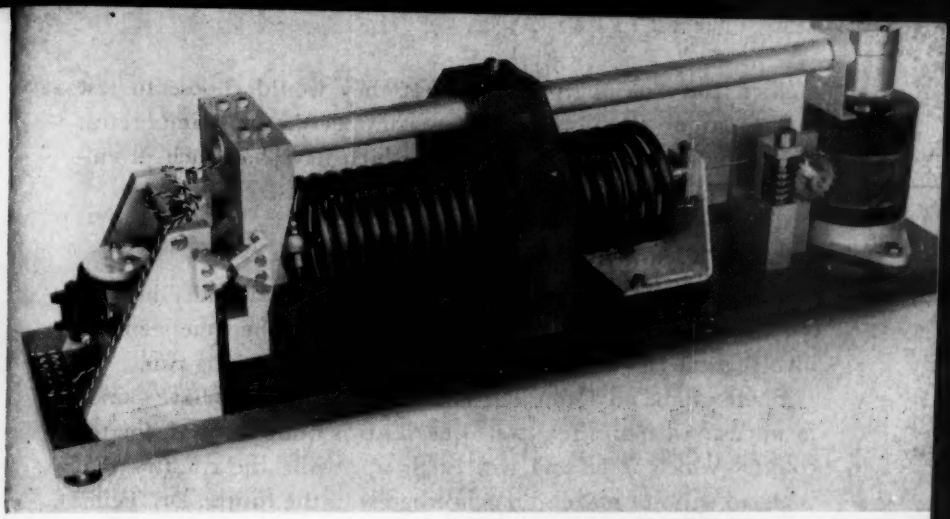
Melton vertical seismometer used in the narrow-band seismograph



New type sealed vault and signal line terminations. Earth covering is removed to expose top of vault

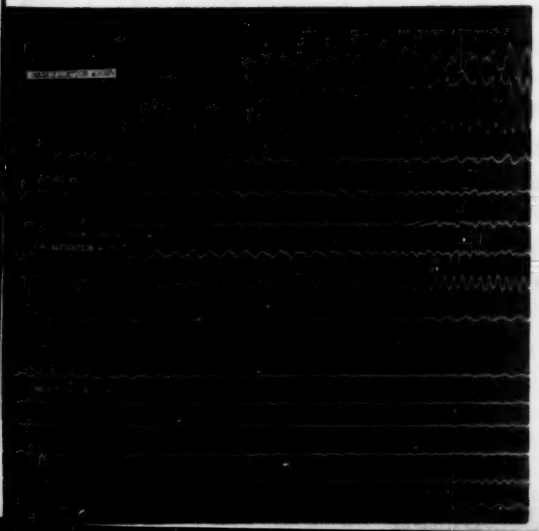


Amplifier building, four storage huts, and the central-recording building



Photographs on these center pages by courtesy of the Advanced Research Projects Agency's Wichita Mountains Seismological Observatory, where they were taken. The observatory, known popularly as the prototype Geneva-model seismic detection station, is operated by the Geotechnical Corporation of Garland, Texas, under technical supervision of the Air Force Technical Applications Center.

▲ Data control console, film viewe and film recorders in the central recording building



◀ A seismic record taken 44,600 ft. from the place of detonation in a salt mine

U.S. Atomic Energy Commission

predict. But I strongly suspect that they would choose to test further large weapons, which they consider the most important, rather than small tactical weapons which have had such prominence in public discussions in the United States.

Risk May Give More Security

Sometimes insistence on 100 percent security actually impairs our security, while the bold decision, which at the time seems to involve some risk, will give us more security in the long run.

There can be no doubt that since 1956 the Russians have gained in nuclear weapons, relative to us. This is quite natural, for the country which is behind will catch up, while the country that is ahead will not make so much progress in the future. Dr. Teller has pointed out that our nuclear weapons today are about 1000 times as efficient as they were in 1945. In the Fall 1960 issue of *Dædalus* he says that "in comparison with the nuclear weapons of 1960, those of 1950 appear completely obsolete. If the development should continue there is no doubt that in 1970 nuclear explosives can be produced compared to which our present weapons will appear similarly outdated." The first sentence is clearly true. But if we want to increase the efficiency of our nuclear weapons by another factor of about ten—not a thousand—beyond the present achievable level, we come to a point where the entire material in the weapon must undergo a nuclear reaction. Since there must be assembly mechanisms, triggers, bomb cases and the like, this is clearly impossible. Further nuclear weapons development will be limited by the laws of physics.

U.S. Stands to Gain by Test Ban

This being so, further testing by both sides would bring the Russian capability closer and closer to ours. If we stop nuclear testing now we may keep at least the little bit of military advantage in nuclear weapons that we still possess at the present time. It is certainly late enough. So that even from the purely

military point of view, for our purely military strength compared to that of Russia, we would gain by a test-cessation agreement.

What is more important, the political gain would be enormous. Basic to the accepted control system of a test ban are the control stations on the territories of the contracting parties. If the agreement becomes reality, the Russians will, for the first time, permit foreign international inspectors to go on their soil to check up on their activities, and to have extraterritorial rights. This is the first time that the Russians have agreed to yield any part of their sovereignty. Of course, we are asked to give up the same part of our sovereignty too, but for the Russians, with their extreme secrecy, this is a far more difficult thing to do and represents quite an achievement in the negotiations.

The Russians have further admitted that there should be on-site inspections whenever there is a suspicious event detected by the physical control stations. This is another major concession. So in the test-cessation agreement we would get the first admission in principle of the rights of a foreign control organ on Russian soil, an admission which might be of the utmost importance for further disarmament agreements. It would be very dangerous indeed for us to jeopardize this achievement by not concluding the test-cessation agreement.

HOW BAN COULD BEGIN

The main importance of our negotiations on the test cessation agreement comes, I believe, not from this agreement itself, important as that is, but from further agreements which must follow. It has been recognized widely in this country and also in Russia that the continued arms race makes no sense. The two countries, Russia and the United States, are fully capable of destroying each other several times over. This is an absurdity. War simply no longer makes sense as an instrument of national policy. I believe we should try to arrive at a situation of carefully controlled

limitation of armaments. It is a difficult thing to achieve and it will be a long time before we achieve it.

However, if we want to stop the armaments race, then we have to make a start somewhere. It has to be made in a way consistent with United States policy, that is, every limitation of armaments must be carefully controlled. We have to make a start in an area where it does not cost us too much, where we can back off again if this first treaty does not work, and this is another reason why the test-cessation agreement is so important.

Keep Nuclear Weapons From China

I have so far discussed this problem entirely on the basis of the two great powers, the United States and Russia. However, the effect on other powers is at least equally important. It is clear that other powers may soon also get nuclear weapons. In fact, if we wait long enough they surely will do so. I do not know how long it will take for Communist China to achieve this capability. I do not think it will be next year, but I should not be surprised if the Chinese would have nuclear weapons before another five years are over. It is to our interest to keep nuclear weapons out of Peiping's possession.

We have every interest in restricting the nuclear club to its present members, essentially three, with France a junior partner. If the three great nuclear powers continue nuclear testing, then there will be no pressure on the other countries to refrain from developing nuclear weapons. If, however, the three great powers give up nuclear testing completely, then popular pressure, both from the great powers and from the small nations, will be very strong on countries that seek weapons in order to make such countries adhere to the treaty which the great powers have signed.

I cannot predict whether Peiping will in fact adhere to a test-cessation treaty. I think that both Russia and the United States would desire that Peiping do so. But one thing seems to me certain. If we do not have a treaty on cessation of nuclear tests, then Communist China will surely get nuclear weapons and will

get them in a fairly short time. For this reason it seems to me imperative not only to have a treaty but also to have it soon.

Perfection May Bring Nothing

At this time we can still get something in return if we agree to stop nuclear testing. But we have a wasting asset here. Before long public opinion in the world will force us to stop nuclear testing without getting anything in exchange. At present we get in exchange acceptance by Moscow of stations on Russia's soil and of the principle of controlled disarmament. We may further get in exchange the restriction of the nuclear club to three members.

Opponents of the test-cessation agreement want to have a perfect agreement: they want to have an agreement which will be sure to detect each and every violation no matter how small. I think that by insisting on perfection we shall end up with nothing.

Discussion Questions

1. How much destruction does an atomic bomb cause at 20 kilotons and at 1 megaton?

2. Why is detection of nuclear explosions easy in air and water? Why is it difficult underground?

3. Is the U.S.S.R. sincere about its interest in cessation of nuclear tests?

4. What has been the policy of the United States on nuclear tests? What technical and political crosscurrents have affected our policy?

5. What are the political advantages of disarmament and nuclear test cessation?

6. What would be the influence of nuclear test cessation on our military position?

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The Case for Continuing Nuclear Tests

by Edward Teller

THERE ARE THREE QUESTIONS CONNECTED with testing of nuclear weapons which deserve careful public discussion. Is it worthwhile to continue testing? Is it feasible to supervise an agreement on test cessation? And what should be done about future nuclear tests?

Expert Judgment Needed

Some of the answers to these questions are of a technical nature. The statements in this field cannot be readily checked by the layman. This is true both because of the complexity of the situation and because of the fact that details concerning nuclear explosives continue to be held as classified information. Secrecy interferes with the formation of public opinion based on objective knowledge. Under these circumstances informed technical experts bear an added burden of responsibility. They must express themselves with as much objectivity as is humanly possible.

It is also obvious that the questions to be discussed are connected with many policy problems which do not lie in the field of the technical expert. Perhaps it might be considered wiser if a technical specialist would abstain from discussing these topics.

On the other hand, the problems mentioned above are closely interwoven and it is hard to draw the line where the technical judgment ceases and the political discussion begins. In fact, it may be preferable to discuss fully the whole complex of questions involved. Such discussion will reveal whatever bias the writer has and will therefore give a more complete picture to the non-technical audience.

IS THE A-BOMB THE ULTIMATE WEAPON?

The power of nuclear bombs surpasses conventional explosives to a degree which is not easily visualized by anyone. It is therefore not surprising that right after the first nuclear explosions the majority of American people, whether they knew much or little about the subject, believed that no further developments would take place. A man who was rightly considered as the greatest expert in this field said toward the end of 1945, "We have accomplished wonderful things in Los Alamos. It will be many years before anybody will be able to improve on them."

Similar prophecies were made in the years that followed. Again and again they have proved to be wrong. I myself frequently have made errors of considerable magnitude when I attempted to forecast future developments. I always erred in the direction of underestimating new possibilities.

New Improvements Go On

The fact is that in the last 15 years we have learned how to increase the explosive force a thousandfold, and we have made great strides in reducing the weight of a bomb of a given power. We have decreased the expense of the biggest nuclear explosives to a point where this expense is no longer an essential factor. On the other hand, small nuclear explosives for tactical purposes are still limited in their usefulness because of their cost. We have made considerable progress in reducing the radioactivity produced by big nuclear explosives, but small nuclear explosives continue to produce the standard amount of radioactivity. We

Our Mark Time Hour Glass

Sandeson in *The Fort Wayne News-Sentinel*

have made nuclear explosives much safer, much easier to handle and much more adaptable to specific purposes. The majority of these purposes are connected with wartime operations such as the sinking of a submarine or the destruction of a plane. All this

has been accomplished by improvements which added each year new and often surprising details to our nuclear devices.

Need for 'Second Strike Force'

The image in the popular mind is quite different. One fact has registered. Instead of kilotons we can now produce megatons. This is not the result of any so-called breakthrough, as is commonly believed, but has been made possible by the steady continuing accumulation of know-how over a period of years. The process of improvement will continue unless research and nuclear testing are discouraged.

At present there is no intention to build bigger nuclear explosives. There is one, and to my mind only one, justification for a great arsenal of megaton bombs: to deter the use of these big explosives against our own country. But if this purpose of deterring attack is to be made really effective we must have what is technically called a "second strike force." This means a force which can survive an all-out nuclear attack on our country and still deliver a counterblow.

It may seem difficult to make sure that our own nuclear explosives and their means of delivery will not be destroyed. But there are several ways in which this can be achieved. A large fraction of our Air Force may be put on continuous air alert. Our bases could be so strengthened as to withstand all but the most accurate hits by the biggest enemy bombs. Finally, we could disperse our counterforce and change the location of our missiles with sufficient frequency so that it would be difficult for an enemy to keep track of them. I believe that the last alternative is the most feasible one.

Once we possess such a second strike force we can eliminate all thought of a "preventive" strike. We need not act on mere suspicion, and we can clearly reiterate that we shall not start an all-out war and shall use our big strike force only in self-defense.

Such a statement could be backed up by adequate civilian defense to safeguard our population and insure our national survival. All of this is possible but quite difficult, and it will require novel and imaginative approaches. One step which will make this program much easier to execute is to decrease the weight of our retaliatory weapons by a considerable factor.

Reduction of Weight Essential

Such a reduction of weight is indeed most important. A second strike force is expensive. Its cost runs to many billions of dollars. It is not easy to protect a missile so that it can survive a megaton attack. It is difficult to move big rockets around the country in complete secrecy. It is expensive to construct atomic submarines which can carry a sufficient number of heavy missiles.

A reduction of the weight of the explosive would reduce the weight of the rocket which has to carry the explosive. This would greatly simplify the task of establishing a second strike force. Whether or not we can construct such a force could well determine our national survival during the next one or two decades. By relatively inexpensive research and by nuclear experimentation which is called testing, we can establish reliable defenses and incidentally save a national effort which is represented by a figure of perhaps $10 billion.

Value of Small Tactical Bombs

Further development of small tactical bombs might be even more important. In a situation where neither of the two greatest powers dares attack its opponent directly, the possibility of limited warfare continues as a menace to peace. Each of the two sides does have a strong interest in limiting the territory and the aims of the conflict in order to avoid an all-out catastrophe. Arguments that nuclear weapons if used anywhere will precipitate all-out war are credible only as long as one or the other side

finds that all-out war is to its advantage. I am certain that we shall not make such a dreadful and insane decision and feel sure the Russians will not either.

One can argue that we should not initiate the use of tactical nuclear weapons in limited warfare. In any case we would put ourselves into a dangerously weak position if we neglected the possibility that the Russians might embark on such limited usage, particularly if we did not have the necessary tactical weapons to use in opposition. Therefore it is an absolute necessity that we should develop tactical nuclear explosives.

We Do Not Know Who Is Ahead

It has been stated that we are ahead of the U.S.S.R. in tactical weapons. Because tactical weapons have low yields, it is difficult if not impossible to observe the testing of such weapons. For example, some of the most interesting tactical explosives have yields less than a thousand tons. Below five thousand tons our observations of Soviet tests are uncertain and incomplete. Below one thousand tons we have at present no means of observation. Therefore we do not know whether we or the Russians are ahead in this important field.

In the United States, interest in tactical nuclear explosions has increased rapidly during the past few years. There are many exceedingly important additional improvements which we now have on the drawing board. Some of these improvements would make our explosives easier to carry and to deliver. Others would make the weapons less expensive and therefore available in greater numbers. Still others would allow us to use nuclear explosives with much greater discrimination. All of these developments also would mean that our requirements for military manpower could be substantially reduced.

These tactical weapons are of low enough yield so that even when used in considerable numbers they do not produce an

excessive radioactive contamination. Further research would make it possible to reduce this contamination to an insignificant level.

Proper development of nuclear weapons could bring about a situation where nuclear warfare need not overhit any target and could be sparing of the lives and the property of noncombatants. Our aim should be to destroy the war machine of the aggressor and to save human lives. It is my opinion that if we continue our present weapons development, this aim can be achieved. However, such a development requires further weapons testing.

Project Plowshare

This discussion would remain incomplete if I did not mention the possibility of peaceful uses of nuclear explosives, which we call Project Plowshare.

There are excellent and convincing experiments and arguments which indicate that these peaceful applications can be carried out, and that they will permit important projects which otherwise would not be feasible or economical. Further development of nuclear explosives could add much to the safety and economic feasibility of Plowshare. For instance, one may use nuclear explosives to move great amounts of earth. One may dig canals or one may blow away hundreds of feet of rock and dirt in order to expose massive deposits of iron or coal for pit mining. For this we need explosives which are cheap, flexible and, above all, clean. We have sound plans to accomplish all this. But we need more nuclear tests.

The field of nuclear explosives is young and challenging. If one side in the world conflict carries out vigorous work while the other remains idle, that side will come into possession of decisive advantages. Our opponent will be better prepared for an all-out conflict, will be superior in limited warfare, and will reap important advantages in peaceful uses of atomic energy.

CAN TEST CESSATION BE POLICED?

A method to detect nuclear explosions in the atmosphere has been functioning for many years. It is true that for smaller shots of approximately a few kilotons this method becomes uncertain. But the situation is relatively easily remedied. Some additional inspection stations and appropriately scheduled flights over the territories of each of the great powers which possess nuclear bombs will allow detection and identification of shots down to one kiloton.

Shots below one kiloton are among the most interesting. These shots could not be detected with assurance by the system which has been proposed at the nuclear conference in Geneva. However, if the shots are in the atmosphere, an unexpected change in wind direction could transport telltale radioactivity toward a control station. It is not necessary to detect every single violation. It is only important to prevent systematic violations. The atmospheric control system is probably good enough to do that.

Nuclear explosions under the ocean are similarly open to detection. In this case it may not be possible to identify the violator, but at least we could have some chance of finding out that a violation did take place.

Atmosphere, Ocean Tests Could Be Stopped —

It would seem to me perfectly reasonable to announce that we will henceforth abstain from weapons testing in the atmosphere and in the ocean. Our action could be unilateral. We would, of course, challenge the U.S.S.R. to do likewise and we should also ask them to support a move in the United Nations requesting all other countries to abstain from this kind of experimentation.

I do not maintain that such a very limited moratorium would have any great advantage. It would actually stop further contamination of the biosphere, the sphere of living beings, by weapons testing. Feelings on contamination are strong throughout

TAMING THE BOMB

Shanks in *The Buffalo Evening News*

'W-What's a plowshare?'

the world, and the Russians themselves have denounced atmospheric contamination.

Moreover, a weapons test moratorium in the biosphere would indeed be a first step which has the great advantage that it can be reasonably well policed. Those who argue that a first step is in itself valuable should support such a proposal.

— But Not Underground Tests

The situation is quite different with respect to underground tests and tests in outer space. Such tests can be carried out without exposing any person to the slightest radioactivity. Moreover, these tests can be effectively hidden in such a manner that even long systematic series of nuclear experiments can be carried out without any real chance that such series will be detected by any technical observation. We have sufficient evidence to make us confident that such series can be used to yield practically all the information which is needed for a successful development of nuclear explosives.

The possibility of detecting underground explosions has received a great deal of attention. The proposed procedure consists in obtaining the locations of underground disturbances by seismographic measurements and in determining by on-site inspection whether such an event has been due to a nuclear explosion or to an earthquake.

We have heard most about the question of how many inspections a year would be permitted. After exceedingly great delays the Russians have suggested three annual inspections in their country. This number is an extremely small fraction of those earthquakes which the seismographs cannot distinguish from nuclear explosions.

Is Inspection Possible?

But further difficulties exist. How will the inspection team determine whether or not a nuclear explosion has taken place? If simple and well-known procedures are followed, the explosion

itself will not leave any mark on the surface. A reliable distinction between an earthquake and an explosion can be obtained only by finding the radioactivity produced by the explosion. This radioactivity, deposited at an unknown depth, will be limited to a few hundred feet from the explosion point. All that the seismographs can tell us is that the event occurred in an area which is approximately one hundred square miles. If the Russians took pains to cover their tracks, we might as well look for a needle in a haystack.

Under these conditions one would have to rely on intelligence information to find out whether or not unusual activities had preceded the earth movement. One would have to find out at what point the shaft or the tunnel had been dug into which the nuclear explosive had been placed. With such information one could indeed find the radioactivity. But at present intelligence work is of questionable value and would lead to considerable friction.

The situation could be improved if the seismograph could distinguish most earthquakes from nuclear explosions. Attempts are being made to find more distinguishing marks, and there is a chance that such attempts will bear fruit. But so far the results are meager. Moreover, it seems possible to distort the signals from a nuclear explosion so that it appears like a natural event.

Muffling of Underground Shots

The difficult question of policing underground shots has become almost hopeless due to the discovery that underground explosions can be muffled or decoupled. By placing nuclear explosives in a cavity of appropriate size the signal can be decreased by a factor of more than 100. This is impressive, particularly if contrasted with possible improvements in the detection system. The most hopeful estimates of such improvements could increase the sensitivity only fivefold.

If a would-be violator should decouple his shots, systematic testing below 20 kilotons could not be detected. To detect shots above 20,000 tons, 600 robot stations in the Soviet Union alone

are needed. Unfortunately there are in Russia each year approximately 5,000 earth movements which would give the kind of signals we are discussing here. Due to the unsatisfactory state of this discrimination between natural earthquakes and artificial ones, practically all of these 5,000 movements would have to be considered suspect. This poses an enormous problem of inspection.

Use of Cavities Practical

But is it, in fact, practical to build the cavities needed for the decoupling? It has been argued that the expense of the excavation would be prohibitive. The process of excavation, it is also said, would be too conspicuous. These arguments are of limited validity.

The cheapest known method of producing cavities of required size is to wash them out from thick salt deposits. Available reliable engineering figures show that a cavity accommodating 20 kilotons can be produced in two years for $10 million. This is not excessive in view of the considerable importance of nuclear tests. The establishment and maintenance of the control system is likely to cost more than the amount which would have to be spent to outwit the technical inspection, even if we consider systematic and extended nuclear test series.

If the excavation is performed by washing out a cavity, the number of people and equipment employed would not be particularly conspicuous. The question of disposing of the salt has been raised. It seems to me that this problem is not very hard to solve. There are many places in the world in which the soil is porous enough so that one can dispose of the salt solution by pouring it on the surface or into relatively shallow holes. The salt might eventually be carried to some source of fresh water, but in appropriately chosen locations one can make sure that this will take a very great number of years.

If muffling could not be effected anywhere except in salt

deposits, the areas which would have to be inspected would be very greatly decreased. Actually it is not too difficult to make an appropriate cavity in limestone. Moreover, the big cavities which are usually discussed are needed only if maximum decoupling is to be attained. Cavities of one-tenth the volume are sufficient to decouple a shot by a factor of 20 or 30. For smaller shots such cavities could be readily excavated by completely conventional methods.

Thus the reader will clearly see that the question of underground detection is complicated. But the following simple summary may serve as a guide.

Systematic violations under one kiloton can be carried out without any difficulty. It is probable that such systematic violations can be extended into the region of a few kilotons and quite probably up to 20 kilotons. Above 100 kilotons systematic violations will almost certainly become extremely difficult to conceal.

Outer Space Testing

It seems strange that so much attention is given to underground testing and all but none to testing in interplanetary space. The latter is theoretically feasible and even more difficult to police.

It is possible to send out a rocket which carries a nuclear explosive as well as observation equipment. Once the missile has attained the appropriate distance from the earth the compartments containing the explosive and observing equipment are separated and allowed to drift apart. When they have drifted apart to an appropriate distance (let us say ten miles) the explosion takes place. The conditions under which the observations are carried out are, of course, quite different from those prevailing on earth. The absence of the atmosphere makes some observations easier, while the absence of heavy equipment will exclude some other measurements. It is clear in any case that significant and

sufficient observations can be performed. The results can then be sent back in a coded form which would not attract any attention. Secret explosions of this kind could be carried out at present up to many megatons.

Problems of Policing

It has been correctly stated that space testing up to a million miles could be policed by methods which seem feasible. A million miles is four times the distance to the moon and is essentially outside the gravitational field of our planet. Once the rocket has left the region of terrestrial gravity it can attain great distances without any further difficulty. If one wants an explosion at 50 million miles from the earth, one has to be patient for a few months and one has to carry an additional power supply of 30 pounds to signal back from the more remote location.

The policing of space tests has been carefully discussed. Policing is possible, but expensive. It is expected to be effective as long as the violator takes no countermeasures to conceal his explosions.

The hiding of space explosions makes it necessary to carry more weight in the rocket. This added weight will cost money. Policing makes it more expensive for the violator to operate, but it continues to permit his operation if the power of the explosion remains under a given limit. This limit in the case of space testing is given by quite a large figure—one-half megaton.

All these statements have been discussed in very considerable detail by American experts. The results have then been submitted to our British and Russian colleagues. Concerning the points I have mentioned above no objection was raised by any party.

It is not easy to make an estimate of the expense of space testing. Twenty million dollars per shot seems to be a reasonable figure. This figure is somewhat higher than the expense of big explosions in the past. It will be further raised if policing is established. However, we should remember that the main expense connected

with space testing is due to the necessity of lifting heavy loads, a task in which the Russians excel.

WHAT ABOUT FUTURE TESTS?

In the two preceding sections I have confined myself to the discussion of known facts and to predictions based on technical knowledge. In this section I shall enter the field of political discussion. It is obvious that my personal judgment will influence my conclusions.

It has been amply demonstrated that if the Russians want to perform systematic clandestine tests they can do so. Whether or not they will do so, I do not know. I have some opinions about the probabilities. So does every one of my readers. A few statements in a discussion cannot change these probability estimates. Therefore a discussion of this topic seems to me futile.

There are, however, some other points where discussion can carry us somewhat farther.

Can U.S. Rely on Russia?

Can we be satisfied with a token inspection and rely on Soviet good will?

To my mind such a procedure is inconsistent. If we are willing to rely on the good intentions of the Russians we have no justification to go to all the trouble, incur all the expense and produce all the friction with which an inspection system is necessarily connected. If the inspection system does not give us any assurance against systematic violations, we should make it clear to ourselves that we are in fact simply accepting the word of the Russians. We may then proceed to consider whether or not we are wise to do so.

But, if our national policy continues to be based on *controlled* arms reduction, it is necessary that we should make the controls meaningful. If we do not do so, we mislead the American public.

The most frequent argument raised in support of a test ban

is the hope that such a ban will be a first step leading to relaxation and further arms control. What has happened during the present two-year moratorium on nuclear tests and nuclear test negotiations does not justify such a hope. The period preceding our test moratorium corresponded to a lull in the cold war. Today militant gestures by Moscow in connection with West Berlin and Cuba, to mention only two points of tension, show an alarming increase in cold-war activities.

Moratorium Without Guarantee Dangerous

If we accept a test moratorium without a guarantee sufficient to insure against systematic Russian evasion, we must seriously consider the possibility that Soviet nuclear tests will put our adversaries into an exceedingly strong military position. Nuclear bombs are not the only weapons which are needed for a strong defense. The possible use of nuclear bombs, however, is inextricably connected with every one of the great dangers which face us. Military power alone will not stop the spread of communism nor will it solve the problems of the world. But if the Russians should secure a sufficiently great military advantage over other great powers, their dream of a Communist world empire might soon be realized. In view of these dangers I believe that we should resume weapons testing in those areas where control is not feasible—both underground and in interplanetary space.

If we resume such testing, what can we do to enhance the expectations of a stable peace? I should like to devote the concluding paragraphs to this question.

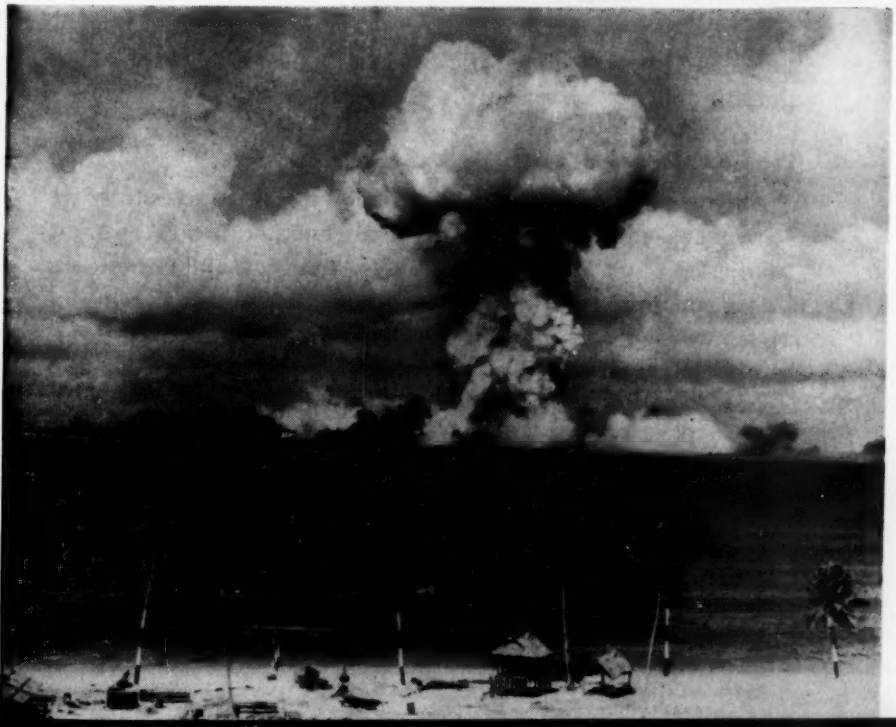
Scientific Secrecy Should Be Reduced

Discussions of the test ban have had a salutary consequence. These discussions have led to a clear realization that arms limitation cannot be insured by purely technical means, and that human contacts between both sides remain paramount. Satisfactory

Nevada Test Site . . . the shot was fired from a 500-ft. tower in Yucca Flat ▶

Courtesy, the U.S. Atomic Energy Commission

Bikini Atoll . . . havoc-producing shock wave sweeps over the target ships and races toward deserted Bikini beach ▼



control of nuclear weapons could be achieved if technological secrecy would be eliminated so that we could learn from Soviet scientists about the status of their weapons research.

In this direction we could make a significant step. We could relax our present rules of secrecy with considerable advantage to ourselves and to our allies. We should use every effort to establish an open world in which the customary scientific interchange replaces the present technological secrecy.

If we reduce secrecy we can more fully participate in building a better world and in fostering the technological progress which promises to assure a decent livelihood for all people on the globe. Similarly, we must participate in the supranational organizations without which technological progress cannot be put to full use. We should be ready to cooperate with everyone, including the Russians, in constructive enterprises which will help to improve the lot of mankind.

As an example of such an activity, I might return to the peaceful use of nuclear explosives which has been called Project Plowshare. Such nuclear shots used for engineering purposes could be performed under international supervision. The purpose of each shot should be stated, and it can be easily demonstrated that the purpose is in fact served by the explosion.

Peaceful Cooperation Urged

Among those projects which can be performed successfully we have mentioned the digging of canals and the use of open-pit mining for critical raw materials such as iron, coal and bituminous substances. There are many who believe that the availability of such raw materials is among the most important factors determining war and peace.

But Plowshare is only one of the fruitful fields we should explore. In weather research, in medical science, and in many other scientific and technical endeavors we can join our friends

and our present opponents in making great and beneficial progress.

Our generation faces a many-faceted problem. We must create a community of nations which is free from coercion and intolerable want. To be able to work toward this goal we need peace. We cannot have peace without strength. At the same time we must use all our power and all our imagination to make the best use of the peaceful years which lie ahead of us.

It is my opinion that a test ban and the cessation of nuclear experimentation would only create an uneasy illusion of security. Real security and real peace can be better reached by developing our technical means, including our nuclear explosives, both for defense and for constructive peacetime purposes.

Discussion Questions

1. What are the principal arguments for disarmament and what are those for preparedness? What is meant by "disarmament" and by "preparedness"?

2. Is one-sided disarmament desirable?

3. Can a ban on test cessation be supervised?

4. What technical developments are likely to result from further testing?

5. Can nuclear explosions be used for peaceful purposes? If so, for what purposes?

6. How are the questions of a test ban, of secrecy and of an open world connected with each other?

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Dr. Bethe Comments on Dr. Teller's Views

Dr. Teller argues persuasively that our military goal must be a "second strike force"—that is, a force which can survive an all-out nuclear attack and still deliver a counterblow. With this conclusion I agree completely, and have agreed in the past.

I do not believe, however, that we need further development of atomic weapons for the establishment of such a second strike force. Our present stockpile of nuclear weapons and those which can be designed on the basis of past tests are adequate. Submarines carrying Polaris missiles are now joining our fleet and will constitute the first, and very important, part of our second strike force. It can be safely assumed that a nuclear warhead for these missiles exists. Plans for mobile missiles on land (Minuteman), to be carried by railroad trains or trucks, are well advanced.

The situation on tactical atomic weapons is similar, although somewhat more complicated.

Agreement — and Disagreement

In order to maintain and improve our military strength we need to develop many new weapons. One of the most ambitious new weapons is an antimissile missile. Another important problem is to provide better communications which would survive during a nuclear attack. These areas of study and experimentation are in my opinion much more important to our defense than further development of atomic weapons. We should also develop modern methods to conduct a limited war without nuclear weapons.

I agree entirely with Dr. Teller's comment that "we should be ready to cooperate with everyone, including the Russians, in constructive enterprises which will help to improve the lot of mankind." However, we should select such areas for cooperation as are likely to be acceptable to the Russians and most useful to

underdeveloped countries. Biology and medicine seem to be obvious choices to help the underdeveloped countries. The non-secret parts of nuclear physics, such as the building of large accelerators, can easily evoke enthusiasm among scientists in both the U.S.S.R. and the United States. The Plowshare project, being connected with atomic weapons, seems one of the more difficult fields of cooperation. Nevertheless, the position of the United States at the Geneva conference has been that Plowshare experiments should be permitted under international inspection and under carefully controlled conditions which would prevent misuse of Plowshare experiments for further development of atomic weapons.

Dr. Teller Answers Dr. Bethe

There can be no question about the correctness of Dr. Bethe's position that Polaris and Minuteman are most essential in the establishment of a second strike force. It is unfortunate that we live in an "Alice in Wonderland" world: we must run very fast to stay in the same place. The main issue between Dr. Bethe and myself is connected with the need and the possibility to run fast.

Visual Aids*

Atomic Timetable, Part II. Produced in 1958 by CBS-TV "See It Now" series. 83 min. Rental, $15.00, from New York University Film Library, 26 Washington Place, New York 3, N.Y. Edward R. Murrow interviews Willard Libby of the Atomic Energy Commission, Hermann Muller, geneticist, Linus Pauling, physicist, and others, who discuss whether continued atomic testing would be a major threat to civilization.

Teller-Pauling Debate: Fallout and Disarmament. Produced in 1958 by KQED, San Francisco. 60 min. Rental, $8.00, from NET Film Services, Indiana University, Bloomington, Ind. Presents a debate on the problem of radioactive fallout from nuclear tests and the advisability of nuclear disarmament. Features Doctors Linus Pauling and Edward Teller.

* Unless otherwise noted, all films are 16 mm, and in black and white.

Glossary

Decoupling: The process of reducing the size of the seismic signals from an underground explosion by detonation of the explosive in a large hole underground.

Kiloton: Explosive energy release corresponding to 1,000 tons of the chemical high explosive, TNT. The bomb detonated at Hiroshima near the conclusion of World War II was equivalent in size to 20 kilotons of TNT.

Megaton: Equivalent of 1,000 kilotons or 1 million tons of chemical explosive (TNT).

Nevada tuff: A weakly cemented, rather crumbly rock, formed from volcanic ash. The underground nuclear explosions of Hardtack II, as well as the Rainier explosion, occurred in this rock, which is somewhat elastic and produces stronger seismic signals from nuclear explosions than are produced by the same size explosions in salt and granite.

Seismogram: The record of an earth tremor.

Seismograph: An instrument for detecting and recording small vibrations in the earth's crust. The detector portion, called a seismometer, usually consists of a mass suspended from a frame either by springs or as a pendulum, in such a manner as to tend to remain in one position while the earth-mounted frame moves with the earth.

Tactical nuclear weapons: Those nuclear weapons ranging in yields below 20 kilotons. This class is often referred to as "low yield weapons."

Threshold: A seismograph of a given sensitivity placed a known distance from an underground explosion or earthquake will record relatively large earthquakes and underground explosions. As the magnitude of the earthquake or equivalent yield of the explosion is reduced it becomes more and more difficult to detect the signature of these events on the seismograph. Eventually one reaches a "threshold" which is defined as the smallest earthquake or underground nuclear explosion which can be clearly detected.

Yield: Energy release.

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